Codling Moth: Blacklight Trapping and Comparisons With Fermenting Molasses Bait and Sex Pheromone Traps

U.S. Department of Agriculture
Agricultural Research Service
Agricultural Research Results•ARR-W-22/August 1981

A copy of this publication is available upon request from the Yakima Agricultural Research Laboratory, 3706 West Nob Hill Boulevard, Yakima, WA 98902.

International Standard Serial Number (ISSN) 0193-3817

Agricultural Research Service, Agricultural Research Results, Western Series, No. 22, August 1981

Published by Agricultural Research Service (Western Region), U.S. Department of Agriculture, Oakland, CA 94612

ABSTRACT

Blacklight (BL), sex pheromone, and fermenting molasses bait (FMB) traps were used to monitor codling moth, *Cydia pomonella* (L.), activity in Yakima County, Wash., orchards for several years. Comparative studies showed that BL and sex pheromone traps were 8 to 104 times more efficient than FMB traps. BL and sex pheromone baited traps were equally attractive in moderately infested orchards, but BL traps were more attractive than sex pheromone traps in heavily infested orchards. Sex pheromone bait attracted moths from a larger area than did BL traps.

Trap location influenced catch significantly. BL traps had to be located inside the tree canopy and in the upper half of the tree. Sex pheromone and FMB traps attracted the most moths when located in the upper half of the tree.

BL traps were an effective sampling method, and their use complemented data obtained with sex pheromone traps. BL traps could have been used for trapping females. Where codling moth populations were heavy or when high temperatures prevailed, BL traps provided more reliable information than did sex pheromone traps.

KEYWORDS: Codling moth, *Cydia pomonella*, blacklight traps, sex pheromone traps, bait traps.

ACKNOWLEDGMENTS

These studies would not have been possible without the assistance of several technicians and professionals over the 18 years involved in the study, especially Austin Clift, J. G. Hartsock, and C. A. Pettibone who designed the BL traps and helped install them; Bill Butt who assisted with the pheromone traps; and D. O. Hathaway who assisted with the FMB traps.

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CODLING MOTH:[1] BLACKLIGHT TRAPPING AND COMPARISONS WITH FERMENTING MOLASSES BAIT AND SEX PHEROMONE TRAPS

By J Franklin Howell[2]

INTRODUCTION

Only three attractants have been used commercially in traps for monitoring codling moth, *Cydia pomonella* (L.), activity and infestations: feeding attractants, such as fermenting molasses baits (FMB); blacklight (BL) irradiation; and sex pheromones. FMB traps were used in Washington State (*21*)[3] until sex pheromone traps were introduced (*6*, *35*) and became the preferred trap for codling moth. Yothers (*39*) found that codling moths were attracted to light, but Marshall and Hienton (*29*) and Hamilton and Steiner (*10*) demonstrated that mercury-vapor (ultraviolet) light was more attractive to the moths. Subsequently, mercury-vapor lights were replaced with fluorescent BL (near ultraviolet) bulbs (*36*).

BL traps were not widely used in the Pacific Northwest for commercial monitoring, but they were used in California (*23*) and Europe (*27*).

In the process of developing "the sterile male technique" of codling moth control, at Yakima, it was necessary to use traps to monitor codling moth populations. At the outset, only FMB and BL traps were available; sex pheromone traps were developed concurrently with the sterile male technique. Therefore, I had the unique opportunity to learn how to use BL traps, and, also, to use them concurrently with sex pheromone traps as sex attractants were researched. Over the past 18 years, a number of unreported observations have been made. My objectives were to report these observations; to describe clearly the conditions for successful BL trapping of the codling moth; and to make comparisons among BL, sex pheromones, and FMB as attractants for the codling moth.

METHODS AND MATERIALS

The BL trap used (fig. 1) was an omnidirectional model identical to the one described by Hienton (*16*, p. 34) except in size; mine was smaller and had a 6-W F6T5•BL lamp instead of a 15-W lamp (the 6-W lamp emits energy in the near ultra-

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[3]Italic numbers in parentheses refer to Literature Cited, p. 11.

Figure 1.--Six-watt blacklight trap used for monitoring codling moth populations in Yakima County, Wash.

violet range (320 to 450 mμ)) (*15*). Both AC and DC traps were of the same design. At first, carbon tetrachloride was used as a killing agent, but this was replaced with one full dichlorvos[4] strip (15 by 6 cm) per trap changed monthly. The bulbs were replaced yearly. The catch was removed from the traps two or three times per week unless noted otherwise. Codling moths were visually separated from other insects in a fume hood at the laboratory by sorting through the entire catch.

Each trap was suspended from a scaffold limb inside the outer portion of the tree, usually at a height of 2.5 m. AC power came from overhead or underground feeder cable (UF). Each trap was grounded. DC power was obtained from a 12V 90-amp-h battery placed at the base of the tree. Converters were used to switch from AC to DC power sources.

FMB traps were prepared and used as described by Hoyt (*21*). The catch was collected two or three times weekly.

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[4]2,2-dichlorovinyl dimethyl phosphate.

Two types of sex pheromone traps were used, the ice cream carton trap (*6*) and the wing trap (*17*). Three sources of pheromone were used: 10 live virgin females per trap, extractions from female abdominal tips (10 female equivalents per trap), and synthetic pheromone in rubber septa (1 mg/septum). The live female moths were obtained from our laboratory colony, which was reared on immature apples (*11*) as were the females from which the tip extracts were taken. The tips were extracted as described by Butt and Hathaway (*6*). The rubber septa were prepared as described by Maitlen et al. (*24*). Trap and attractant used will be specified in the results.

BL Trap Attractancy

To determine the percentage of codling moths attracted to BL, marked virgin moths of both sexes (12 to 24 h old), which were laboratory reared, were released (1) in a greenhouse, (2) in a backyard orchard of eight trees with one BL trap per tree, and (3) at White Swan, Wash., in a 6-ha orchard with 18 traps set to transect the orchard along the cardinal directions; traps in the transect were 27.5 m apart. The greenhouse was sealed to confine moths in close proximity to the BL trap. Moths were released in the center of plots in the orchards. There were two replicates each. A third test, replicated six times, was run in the 6-ha orchard with moths that were irradiated or treated with tepa[5] (*12*, *13*).

BL Trap Location

To determine the best location for the BL trap, four locations were tested: in open areas (missing tree space), in the tree canopy, and at two heights (2.5 and 4 m).

In a 6-ha orchard of Winesaps, 18 BL traps were installed in transects along cardinal directions from the center of the orchard--four traps north and south, five traps east and west. The traps were 27.5 m apart. Where trees were missing, traps were hung from poles at the same height as in the trees; that is, 2.5 m. The catch was removed twice weekly.

In a city lot with eight Winesap trees, BL traps were tested at 2.5 and 4 m high, four traps per height. The catch was collected daily from August 28 to September 19.

BL and FMB Trap Comparisons

In 1964, catch comparisons were made between BL and FMB traps in an orchard at Yakima and White Swan at 4:1 and 3:1 tree-to-trap ratios, respectively. FMB

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[5]Tris (1-aziridinyl)phosphine oxide.

traps were 3 to 4 m high (in the top of the tree) and BL traps were at 2.5 m. In 1967, BL and FMB traps were compared in a 1-ha abandoned orchard (Dahlke's) in Yakima at about a 7:1 tree-to-trap ratio, four replicates of each. The traps were relocated randomly every 4 days among 28 possible positions in the orchard. The traps were between 2 and 2.5 m above the orchard floor. In each test, equal numbers of BL and FMB traps were used.

BL and Sex Pheromone Trap Comparisons

Comparisons were made at White Swan in 1964 using the BL trap transects as described earlier, four and five traps in each direction from a pivot point. The sex pheromone traps were ice cream carton (quart) traps baited with tip extracts (6). The eight sex pheromone traps were scattered throughout the orchard. On July 22, the number of sex pheromone traps was increased to 100, or a 2.4:1 tree-to-trap ratio for sex pheromone traps. The study was repeated in 1965 using 13 sex pheromone traps (18:1 tree-to-trap ratio) baited with 10 virgin females per trap. The females were replaced every 5 days from the laboratory colony. In 1966, the 18 BL traps were compared with 5 sex pheromone traps (48:1 tree-to-trap ratio) from the first emergence of moths to July 25, when the sex pheromone traps were increased to 1 per tree. All traps were baited with 10 live virgin females, which were changed at 5-day intervals.

In 1967 and 1968, the comparison was between one BL trap and eight sex pheromone traps arranged concentrically around it (radii of 18 to 91 m). At 18 m, there were three replicates, but at 91 m, only one (but repeated four times, once in 1967 and three times in 1968). The positions of the sex pheromone traps were rotated every second week. These sex pheromone traps were baited with 10 live virgin females per trap.

An experiment similar to the BL and FMB trap comparison between sex pheromone traps and BL traps using the same factorial design was conducted at Dahlke's in 1967. The source of pheromone was 10 live virgin females per trap. Trap locations were rotated on a 4-day schedule.

At Yakima, in 1980, five BL traps and five pheromone traps baited with synthetic sex pheromone (1 mg) were alternately placed, one per tree, in a row of pear trees in the laboratory orchard. Trap position was rotated weekly. The traps were serviced, and the catch was collected daily. The septa containing the synthetic sex pheromone were replaced monthly with new ones.

Both the BL and the sex pheromone traps in these comparisons were at a height of about 2.5 m in the tree.

RESULTS

BL Trap Attractancy

Of the 300 moths released in the greenhouse, 52.7 percent were trapped. During the first 3 nights, in one release 24, 55, and 59 moths were trapped and 29, 15, and 9 moths were resting on the trap, respectively. In the second trial, 45 percent were trapped and 11 percent were observed resting on, but not entering,

the trap. In the two releases, 12 and 14 percent of the moths were injured and unable to fly. In the backyard orchard, 595 moths were released and 18.8 percent were trapped (one trap per tree, table 1). In the 6-ha orchard at White Swan, 736 were released and 9.1 percent were trapped.

Table 1.--*Blacklight attractancy to codling moths in a Winesap apple orchard, 1 6-W BL trap per tree (8 trees)*

Date	No. released		No. trapped		Percent trapped		Percent total
	Male	Female	Male	Female	Male	Female	
July 13	[1]50	[1]50	18	6	36	12	24
18	[1]100	[1]100	14	0	14	0	7
28	[2]45	0	21	0	47	0	47
Aug. 4	[2]50	0	18	0	36	0	36
11	[2]50	[2]50	8	20	16	40	28
24	[2]50	[2]50	4	3	8	6	7

[1]Irradiated, 40 krad.
[2]Sterilized with tepa.

BL Trap Location

BL traps were not very attractive outside the tree canopy. Inside the canopy, they caught 13.4 moths per trap per night; those on poles outside the canopy caught 0.9 moths per trap per night.

Traps 2.5 m high caught 13.0 moths per trap per night compared with the 4-m-high traps that caught 4.3 moths per trap per night. If the data were compared monthly, the low trap caught more moths than the high trap in August, but both traps caught equal numbers of moths in September.

BL and FMB Trap Comparisons

The results of comparative trap catches are presented in table 2. In addition to results concerning traps run concurrently in the same orchard, annual trapping records from other locations were included as supporting evidence to show that FMB traps gave similar catches in several locations. Each orchard was abandoned and had high moth populations (carrying capacity).

BL and Sex Pheromone Trap Comparisons

The average number of males caught in each trap each year is presented in table 3.

Table 2.--*Comparative catch of codling moths caught in traps baited with blacklight (BL) or fermenting molasses bait (FMB)*

		Average No. of males caught per trap per day[1]	
Location	Year	BL trap	FMB trap
Upper Valley A	1963		1.1
Upper Valley B	1963		.6
Yakima	1963	3.8a	.1 b
Lower Valley	1963		1.3
White Swan	1963		2.9
	1964	10.7a	1.3 b
Dahlke	1967	52.1a	.5 b

[1]Statistical comparisons were at the 5 percent level of confidence, and were only between trap types for a given year.

Table 3.--*Comparative catch of codling moths caught in traps baited with blacklight (BL) or sex pheromone*

		Average No. of males caught per trap per day[1]			No. traps	
Location	Year	BL trap	Sex pheromone trap	Source of pheromone	BL	Sex phermone
White Swan	1964	6.5a	12.7 b	tip extracts	18	8
		18.5a	.9 b	--do--	18	100
	1965	2.5a	3.1a	live females	18	13
	1966	.7 b	3.2a	--do--	18	5
		3.4a	.4 b	--do--	18	244
Yakima	1966	5.2a	6.3a	--do--	1	1
White Swan	1967	8.3a	4.9 b	--do--	1	8
	1968	5.7a	5.7a	--do--	1	8
Dahlke	1967	52.1a	14.9 b	--do--	3	3
Yakima	1980	4.4a	1.5 b	synthetic	5	5

[1]Statistical comparisons were at the 5 percent level of confidence, and were only between trap types for a given year.

DISCUSSION

BL Trap Attractancy

In the greenhouse, when the data were adjusted for the observed mortality, 64 percent of the moths were attracted to the BL trap in a 5-day period. The trap catch increased daily for 3 days, indicating that 2- and 3-day-old moths were more attracted than day-old moths. Based on the number of moths resting on the exterior of the trap, some were attracted to the trap but never entered it.

For a discussion on the age of codling moths attracted to sex pheromone traps, refer to (*20*).

In the tests with one trap per tree, recovery averaged 19 percent (range, 7 to 47 percent); with a 1:13 trap-to-tree ratio, recovery averaged 9.1 percent at densities of 595 and 736 moths. Percent recovery of released moths was trap-density dependent.

The presence or absence of female moths in the orchard made a difference in the percentage of recovery. The average recovery when both sexes were released was 16.5 percent compared with 41.5 percent when only males were released. A higher percentage of males than females was trapped, reflecting male searching behavior or higher activity. When females were present, they represented a second source of attractant and were competitive with the BL traps, just as females competed with sex pheromone traps (*18*).

BL Trap Location

Hamilton and Steiner (*10*) tested the effect of position of BL traps on catch, specifically above the tree and in the top of the tree, and found that catches were lower above the tree than in the top of the tree; however, they did not test intermediate or low level trap positions in the tree. Since moths were equally or more attracted to the light in the low position, which made servicing easy, the low position was used routinely thereafter; however, D. O. Hathaway (unpublished manuscript) found the Kitterman sex pheromone trap most effective at 3.6 m or near the top of the tree.

McNally and Barnes (*30*), using Pherocon 1 CP traps, found that more moths were caught at 4 m than at 3 m, but differences were not statistically significant. The difference between 2 and 3 m was not significant, but between 2 and 4 m there was a significant difference. Reidl et al. (*34*) found that their traps were most efficient when they were in the upper third of the tree, regardless of tree height. Charmillot (*9*), however, found sex attractant traps caught the most moths at 2 m, or midtree. He also found that mating with tethered females was more frequent at the midtree level.

My own observations, using marked moths and ultraviolet light for illumination, showed that mating in a caged tree was not concentrated in the top of the tree. Bobb et al. (*4*) also reported that FMB traps caught more moths when the traps were in the top of the tree. The best location for sex pheromone traps

seems to be uncertain at the moment, but certainly it appears that the trap should be in the upper half of the tree. In my studies, BL traps were usually at mid-level or in the upper half of the tree. BL traps on poles outside the canopy of the tree were not attractive to many moths (one-thirteenth the number attracted within the canopy). Mani and Wildbolz (*28*) observed a similar response for sex pheromone traps. When moths do leave a tree, they are attracted to silhouettes of other trees, the silhouette is apparently more attractive than the BL or sex pheromone traps (*26*, *28*). Therefore, any trap regardless of type of attractant used, seemed more proficient inside the tree canopy, as was demonstrated for BL traps.

BL and FMB Trap Comparison

FMB traps were more difficult to use than BL traps. In FMB traps, the trapped moths had to be recovered from the liquid and the bait evaporated. It was necessary to replenish or replace the bait regularly. Fermentation was uncontrollable; consequently, attractancy was variable and unpredictable. The bait was easily spilled and containers decayed rapidly and required frequent replacement. Since the traps could not be tipped sideways, they had to be raised and lowered using a rope.

FMB traps in abondoned orchards where moth populations were at capacity, caught about one moth per day. BL traps were 8 to 104 times more effective than FMB traps (table 2).

BL and Sex Pheromone Trap Comparisons

With equal numbers of trap sets, BL trap catches were equal to or better than sex pheromone trap catches (Yakima 1966, 1980 and Dahlke 1967, table 3). When pheromone traps outnumbered the BL traps 8:1, BL catches were again equal to or better than sex pheromone trap catches (White Swan 1967, 1968). When there were fewer sex pheromone traps than BL traps (about 1:2 or 1:4), the catch was equal (White Swan 1965) or better (White Swan 1964, 1966) in the pheromone traps. With a large number of sex pheromone traps in limited space, the catch-to-trap ratio dropped sharply, but the total number of moths caught per hectare increased (White Swan 1964, 1966). The same was not observed for BL traps, but BL traps were never as concentrated as the sex pheromone traps. These data suggest that any BL or sex pheromone trap is competitive with any other trap present; Howell (*18*) and Howell and Clift (*19*) showed that female moths competed with sex pheromone traps and that the competition increased as the population increased.

Although sex pheromone trap catches continued to increase as the area per trap increased up to 9 ha (*33*), which implies higher efficacy, according to my data, the percentage of moths trapped per unit area decreased (table 3). (Increased number of traps per hectare increased total numbers caught but reduced the number caught per trap.) This concept needs to be carefully considered when recommending a standard trap density. Best density really depends upon the objective of the test or the application for which the results are to be used.

Other data showed that the BL traps worked as well as sex pheromone traps. For instance, White et al. (*37*) found that BL traps recovered about 2 percent fewer released males than traps baited with synthetic pheromone. White et al. (*38*), using one pheromone trap/0.7 ha, recovered 9.45 percent of the released males; that compared favorably with the release-recovery of 9.10 percent using one BL/1.6 ha. In 1966, at White Swan, I found that two pheromone traps per hectare reduced the number of males caught in BL traps by 20 percent. Audemard and Milaire (*1*) estimated that three pheromone (synthetic) traps per hectare caught 25 to 35 percent of the males, which compares favorably with the White Swan catch.

BL traps effectively attracted codling moths for up to 30 m (*19*), whereas sex pheromone traps attracted moths from 91 m away (Howell, unpublished data). This difference in attraction distance would have been one reason for the differences in percentage catch; that is, 9.1 percent for BL traps compared with 20 to 35 percent for sex pheromone traps when the trap densities were similar (2 to 3 traps per hectare). A single sex pheromone trap in a 5-ha orchard with few codling moths, however, was more efficient than a single BL trap, perhaps because of its greater radius of attraction.

In preparing this paper, the question of relative attractiveness of virgin females and synthetic pheromone repeatedly arose. Literature and tests indicated that the difference in the relative attractancy of sex pheromone from virgin females and synthetic sex pheromone has not been defined. Comparative results between attractancy of virgin females and synthetic pheromone have been erratic.

Butt et al. (*7*) found that virgin females were more attractive but that the synthetic sex pheromone contained a number of inhibitory isomers (*35*). Madsen and Vakenti (*22*) found that synthetic pheromone was superior in attractiveness to virgin females early in the season but that they were similar in attractiveness later in the season. Batiste et al. (*2*) found live virgin female moths and synthetic sex pheromone were equally attractive. Mani et al. (*25*) found the synthetic pheromone equal (1972), and then superior (*27*), to virgin females (1975). Madsen and Vakenti (*22*) used one sex pheromone (1 mg) and one live virgin female trap per tree (five females per trap). In 1972, Mani et al. (*25*) had from 30 to 50 m between traps, but in 1975 Mani and Wildbolz (*27*) used two sex pheromone traps, two live female (five females per trap) traps, and one BL trap per station. Both Madsen and Vakenti (*22*) and Mani and Wildbolz (*27*) considered the synthetic sex pheromone trap superior to the live virgin female baited trap.

Cardé et al. (*8*) and Hathaway et al. (*14*), however, demonstrated that the synthetic pheromone in the vicinity of a virgin female trap disrupted the attractancy of the virgin females, and as a result, virgin female baited traps caught very few males. It can be concluded that the experimental design used by Madsen and Vakenti (*22*) and Mani and Wildbolz (*27*) may have disrupted the catch in virgin female baited traps. The Mani et al. (*25*) 1972 test minimized disruption, and in that test there was comparability between synthetic sex pheromone, virgin female, and BL traps. At Yakima, 10 live virgin females, which should have been more attractive than the 5 virgin females used by Madsen and Vakenti (*22*) and Mani et al. (*25*, *26*), were used to bait traps; that may have been the reason why both pheromone sources were similarly attractive in my tests.

Since the male is entrained to the same rhythmic mating period as the female (*3*), the synthetic sex pheromone has no advantage in attractancy over virgin females, but there may be disadvantages, such as habituation, different emission rates, and nonoptimal concentrations.

The question of how synthetic sex pheromone compared with wild virgin females was not resolved. In properly designed tests, where two sources of sex pheromone did not interfere with each other, their attractiveness seemed comparable; however, the synthetic sex pheromone was found to be more practical. Available data suggest that the synthetic sex pheromone and virgin females had comparable attractancy.

Properly designed and operated BL traps were comparable or superior in attractiveness to live females or synthetic sex pheromone baits in my tests (table 3). Batiste et al. (*2*) showed BL trap superiority over virgin female baited traps at Placerville. The comparisons made involved males only; however, BL also caught females. In 1980, at Yakima, the BL traps caught as many females as males in the synthetic sex pheromone baited traps (1.99 females versus 1.54 males per trap per day).

Howell (*18*), Madsen and Vakenti (*22*), Mani and Wildbolz (*27*), and Riedl (*32*) noted that sex pheromone traps were more efficient in spring than in summer months. When BL and sex pheromone traps were operated concurrently in an orchard, the BL trap catch increased as the sex pheromone trap catch decreased. A positive correlation between catch and temperature for BL traps existed: higher temperatures gave increased catch. Sex pheromone trap catches varied from no correlation to a negative correlation with temperature. Reduced sex pheromone trap efficiency in the summer possibly resulted from (1) larger populations and increased competition from native females (*18*), (2) a negative response to high temperature (fig. 2) (*5*), and (3) disrupted or confused communication with the trap because of increased emission rates at higher temperatures (*9*). When working in a warm region, a locality where the average spermatophore count per female is >1.5, the assumption should be followed that the moth population is higher than indicated by the sex pheromone trap catch during the summer months (July and August at Yakima).

Howell (unpublished data) and Riedl (*33*) found that males were attracted 91.5 and about 270 m, respectively, to pheromone traps. Howell (unpublished data) found that 90 percent of the moths attracted to BL were from a radius of 30 m. Therefore, sex attractant traps would have sampled a commercial orchard more effectively than BL traps at low trap densities. Within that 30-m radius, however, BL traps were equally competitive with sex attractant traps.

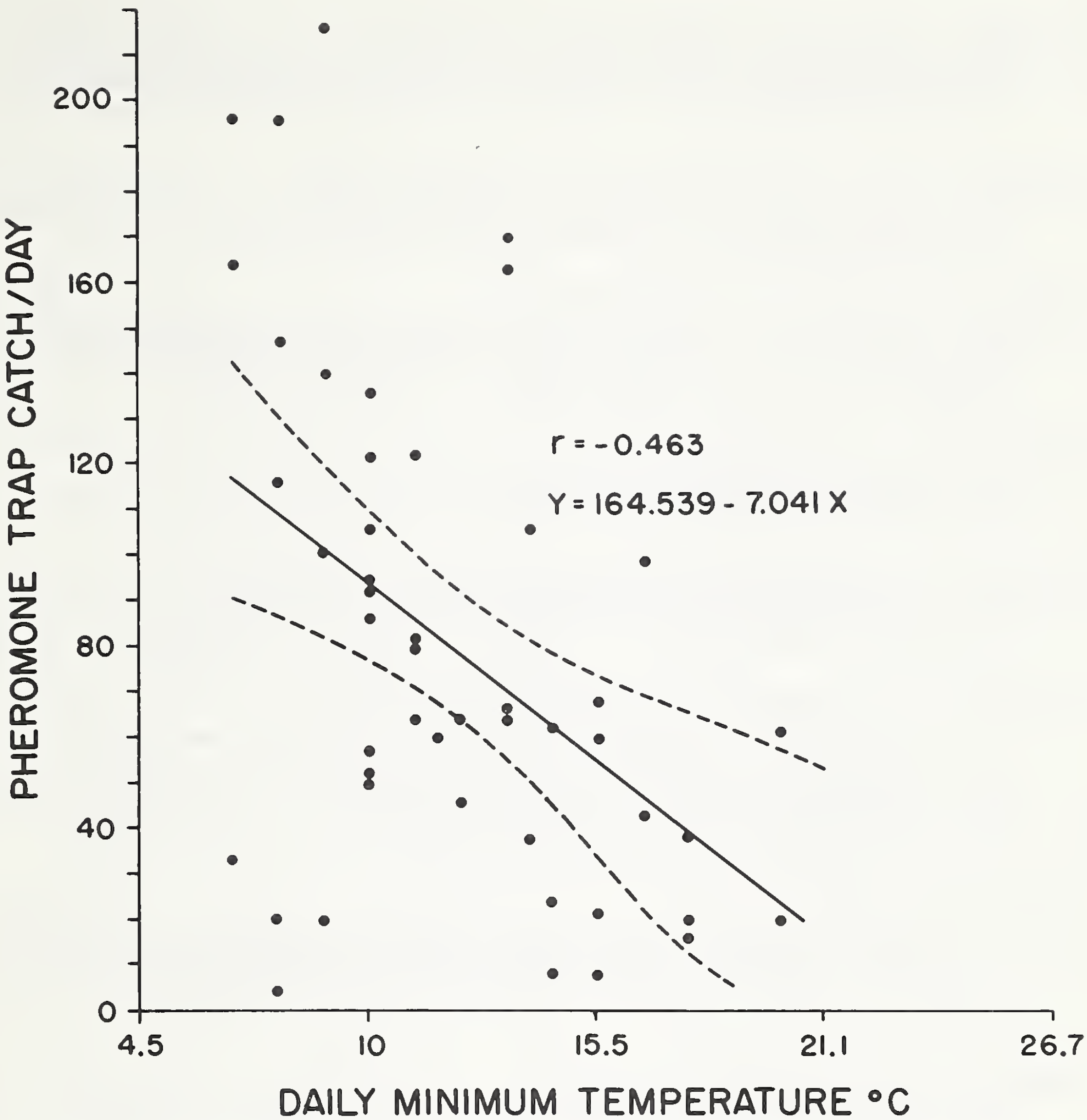

Figure 2.--Regression showing the relationship between codling moth catch in pheromone traps and daily minimum temperatures, Yakima Co., Wash.

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